

CLAIMS

What is claimed is:

1. A method for restoring a part which has lost first material from a site comprising:
placing the part in a deposition chamber;
applying a first electric potential to the part;
evaporating components for forming a repair material
ionizing the evaporated components; and
modulating the first electric potential so as to draw the ionized components to the part
so that buildup of the repair material at least partially replaces the first material.
2. The method of claim 1 wherein:
the part is a Ti alloy turbine part and the repair material is Ti-based.
3. The method of claim 1 wherein:
the modulating is performed so as to prevent arcing from the part.
4. The method of claim 1 further comprising:
heating the part; and
modulating the heating of the part in conjunction with the modulating of the first electric potential.
5. The method of claim 1 wherein the modulating comprises:
maintaining a principally negative potential; and
applying positive pulses of relatively short duration.
6. The method of claim 1 wherein:
the ionizing is modulated.
7. The method of claim 1 wherein:
the method further comprises removing additional material at least partially from the site to create a base surface; and
the physically depositing deposits said repair material atop the base surface at least partially in place of the first material and the additional material.

8. The method of claim 1 wherein:
said deposited repair material in major part replaces said first material.
9. The method of claim 1 wherein said repair material comprises Ti-6Al-4V, Ti-6Al-2Sn-4Zr-2Mo, Ti-8Al-1V-1Mo, or Ti-6Al-2Sn-4Zr-6Mo.
10. The method of claim 1 wherein the removing of additional material is, in major part, from undamaged portions of the part.
11. The method of claim 1 wherein the part is a blade having a root and an airfoil and the site is along a leading edge of the airfoil inboard of a midspan shroud of the airfoil.
12. The method of claim 11 wherein the first material is lost to a depth of at least 2.0 mm.
13. The method of claim 1 further comprising:
applying a backing element to the part protruding adjacent the site so that the deposited repair material builds up on the base surface and backing element.
14. The method of claim 13 further comprising:
at least partially removing the backing element and machining adjacent deposited material and preexisting material of the part to create a second base surface; and
physically depositing more of the repair material atop the second base surface.
15. The method of claim 1 performed at a pressure less than 0.01 Pa.
16. A method for restoring a Ti alloy part which has lost first material from a site comprising:
placing the part in a deposition chamber;
applying a first electric potential to the part;
ionizing components for forming a Ti-based repair material; and
modulating the first electric potential so as to draw the ionized components to the part while maintaining a temperature of the part within a target range so that buildup of the repair material at least partially replaces the first material with desired properties.

17. The method of claim 16 wherein the first electric potential has:
 - a nominal voltage of 50V-10kV;
 - a pulse repetition frequency of 0.05-150kHz;
 - a pulse width of at least 5 μ s;
 - a duty cycle of 0.1-0.99; and
 - an ion current density of 1-50mA/cm² at a deposition rate of 10-50 μ m/minute.
18. The method of claim 17 wherein:
 - the nominal voltage is 1-3kV;
 - the pulse repetition frequency is 0.5-5kHz; and
 - the ion current density is 2-10mA/cm² at a deposition rate of 15-20 μ m/minute.
19. The method of claim 16 wherein:
 - the ionizing is pulse modulated with a pulse repetition frequency of 100-1000Hz and a duty cycle of 0.5-0.9.
20. The method of claim 16 further comprising:
 - heating the part; and
 - modulating the heating of the part in conjunction with the modulating of the first electric potential.
21. The method of claim 16 wherein the modulating comprises:
 - maintaining a principally negative potential; and
 - applying positive pulses of relatively short duration.
22. An apparatus for depositing material on a workpiece comprising:
 - a deposition chamber;
 - a deposition material source;
 - means for forming a plasma from said deposition material source;
 - means for applying a modulated bias electric potential to the workpiece to draw ions from the plasma to the workpiece;
 - means for monitoring a density of the plasma and an ion current to the workpiece; and
 - a control system coupled to the means for forming, means for applying, and means for monitoring and programmed so as to provide feedback loop control of deposition of the

material.

23. The apparatus of claim 22 further comprising:
means for heating the workpiece.
24. An apparatus for depositing material on a workpiece comprising:
a deposition chamber;
deposition material at least partially within the deposition chamber;
a first electron beam source, positioned to direct a first electron beam to vaporize a portion of the deposition material;
an ionizing electrode and an electromagnetic coil surrounding a flowpath from the deposition material;
a bias voltage source connected to apply an electric potential to the workpiece; and
a control apparatus coupled to the bias voltage source and configured to apply said electric potential as a principally negative potential interspersed with positive pulses.
25. The apparatus of claim 24 wherein:
the control apparatus is coupled to the ionizing electrode for pulse modulation of ionization.
26. The apparatus of claim 24 wherein:
the bias voltage source or comprises an electronic tube acting to limit current to the workpiece.
27. The apparatus of claim 24 further comprising:
a second electron beam source positioned to direct a second electron beam to the workpiece.
28. The apparatus of claim 24 wherein:
the deposition material comprises Ti, Al, and V.
29. A repaired metallic part comprising:
a substrate; and
a repair material having a first interface with the substrate, a bond strength between

the repair material and the substrate being in excess of 50 ksi.

30. The part of claim 29 wherein the repair material is a first repair material and wherein the part further comprises:

a second repair material having a second interface with the substrate and a third interface with the first repair material, second and third bond strengths between the second repair material and the substrate and first repair material, respectively, being in excess of 50 ksi.

31. The part of claim 29 wherein:

the substrate and the repair material comprise Ti alloys or nickel- or cobalt-based superalloys of like nominal composition;

the bond strength is between 100 ksi and 200 ksi;

the repair material has a depth of at least 2.0 mm;

the substrate has a thickness in excess of the depth of the repair material; and

the substrate comprises original unrepaired material.